High p_T Jets and Photons at the Tevatron

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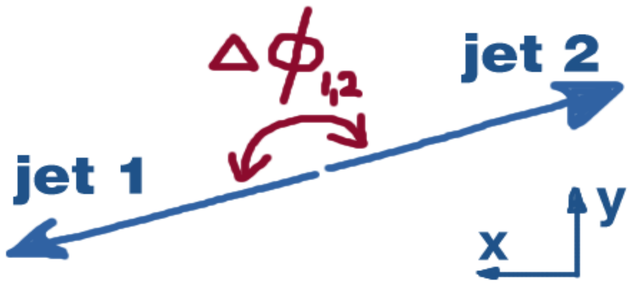
Outline

- Jets
  - Dijet azimuthal decorrelation
    - D-Zero result accepted by PRL
- b-Jets
  - SecVtx & muon-tagged jets
    - New CDF & D-Zero results Spring 2005
- Photons
  - Prompt Diphoton Cross Section
    - CDF result accepted by PRL
  - Isolated Photon Cross Section New
    - New D-Zero result for this conference

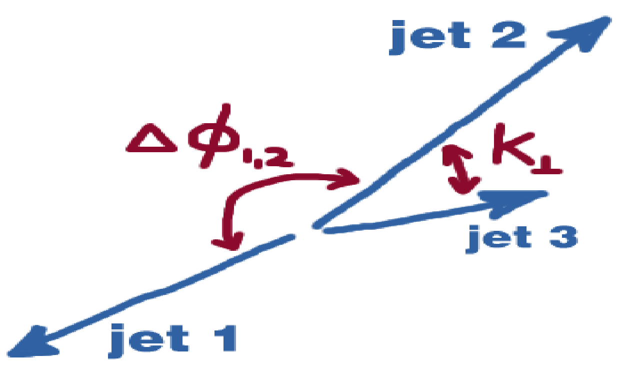
Dijet $\Delta\phi_{12}$ Distributions

- No radiation
  - 2 jets of equal p_T
  - Correlated $\Delta\Phi_{12} = \pi$
- Soft radiation
  - $\Delta\Phi_{12} \approx \pi$
  - pQCD diverges ($k_T \rightarrow 0$)
- Hard radiation
  - $\Delta\Phi_{12} << \pi$
- Exclusive 3-jet production
  - $2\pi/3 < \Delta\Phi_{12} < \pi$
- Events with ≥ 4 jets
  - $\Delta\Phi_{12} < 2\pi/3$

Dijet production in lowest-order pQCD



3-jet production in lowest-order pQCD



$\Delta\phi_{12}$ distribution is directly sensitive to higher order QCD radiation without explicitly measuring the third jet

Dijet Azimuthal Decorrelations

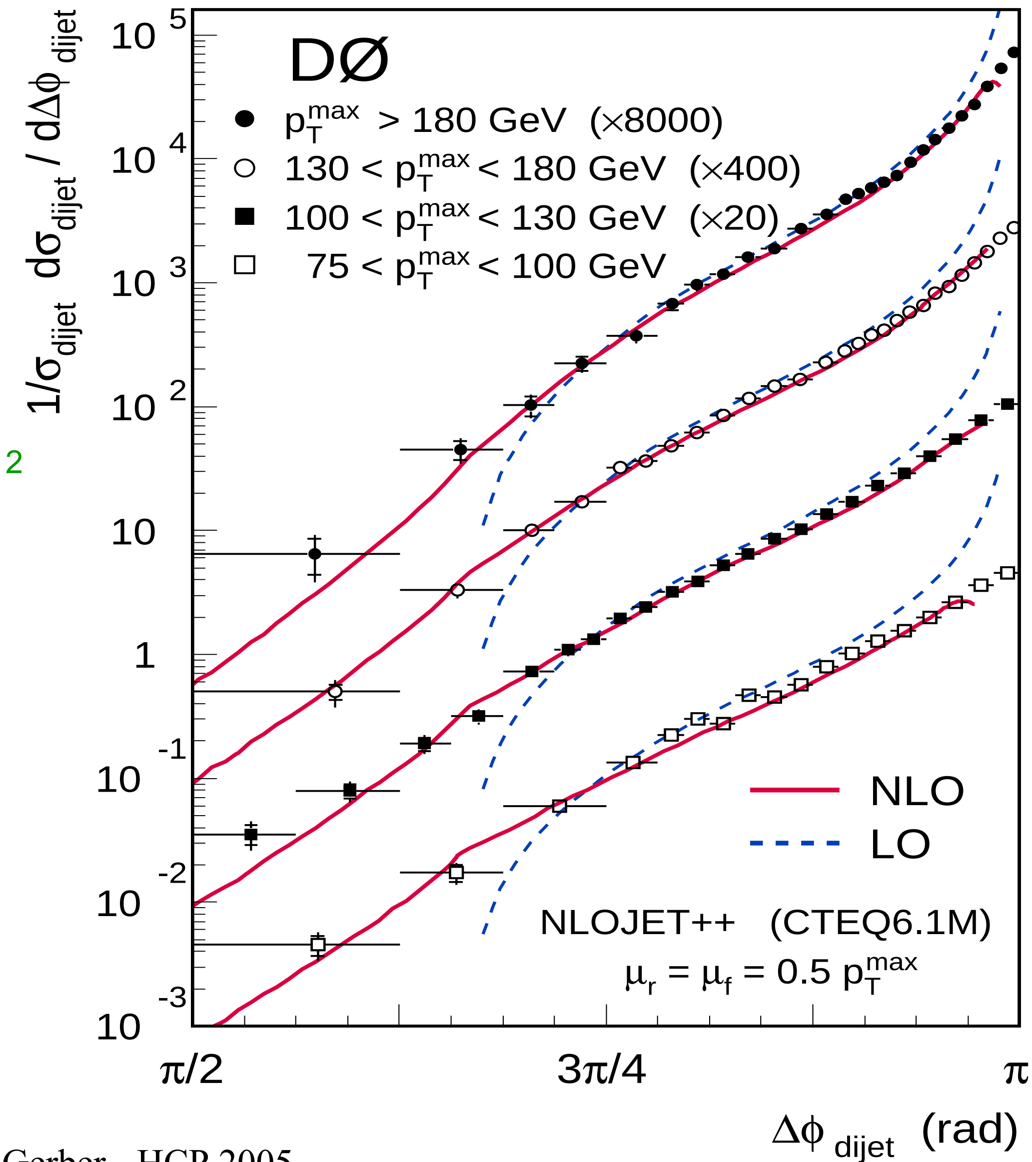
accepted by PRL, hep-ex 0409040

- Jets are reconstructed with an iterative seed based cone algorithm including mid-points with $R_{cone} = 0.7$
  - Used for partons in pQCD calculations, final-state particles in MC event generators and energy depositions in the calorimeter
- Leading Jet p_T > 75, 100, 130 and 180 GeV
  - define 4 analysis regions
- Second leading jet p_T > 40GeV
- Both jets have $|y| < 0.5$
- $\int \mathcal{L}\, dt \sim 150\ \mathrm{pb}^{-1}$

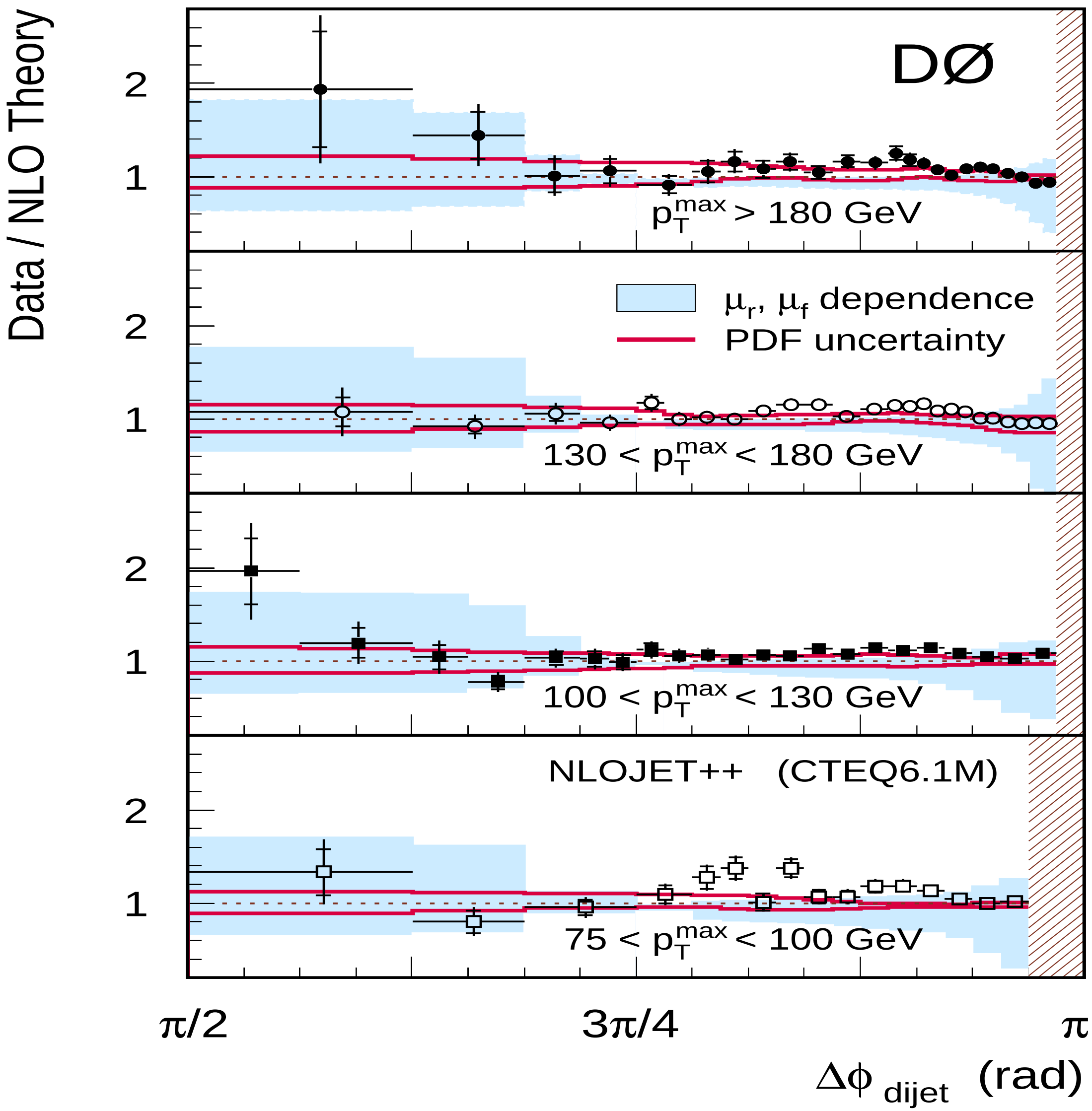
Dijet Azimuthal Decorrelations

$$\frac{1}{\sigma_{dijet}} \frac{d\sigma_{dijet}}{d\Delta\phi_{dijet}}$$

- $\Delta\Phi$ spectra more strongly peaked at ~ π for larger p_T,
  - Increased correlation in $\Delta\Phi_{12}$
- LO 3-jet production
  - Divergence at $\Delta\Phi_{12} = \pi$ when 3rd jet is soft
  - No phase-space at $\Delta\Phi_{12} < 2\pi/3$
- NLO 3-jet production
  - Good description
  - Fixed order QCD fails at π



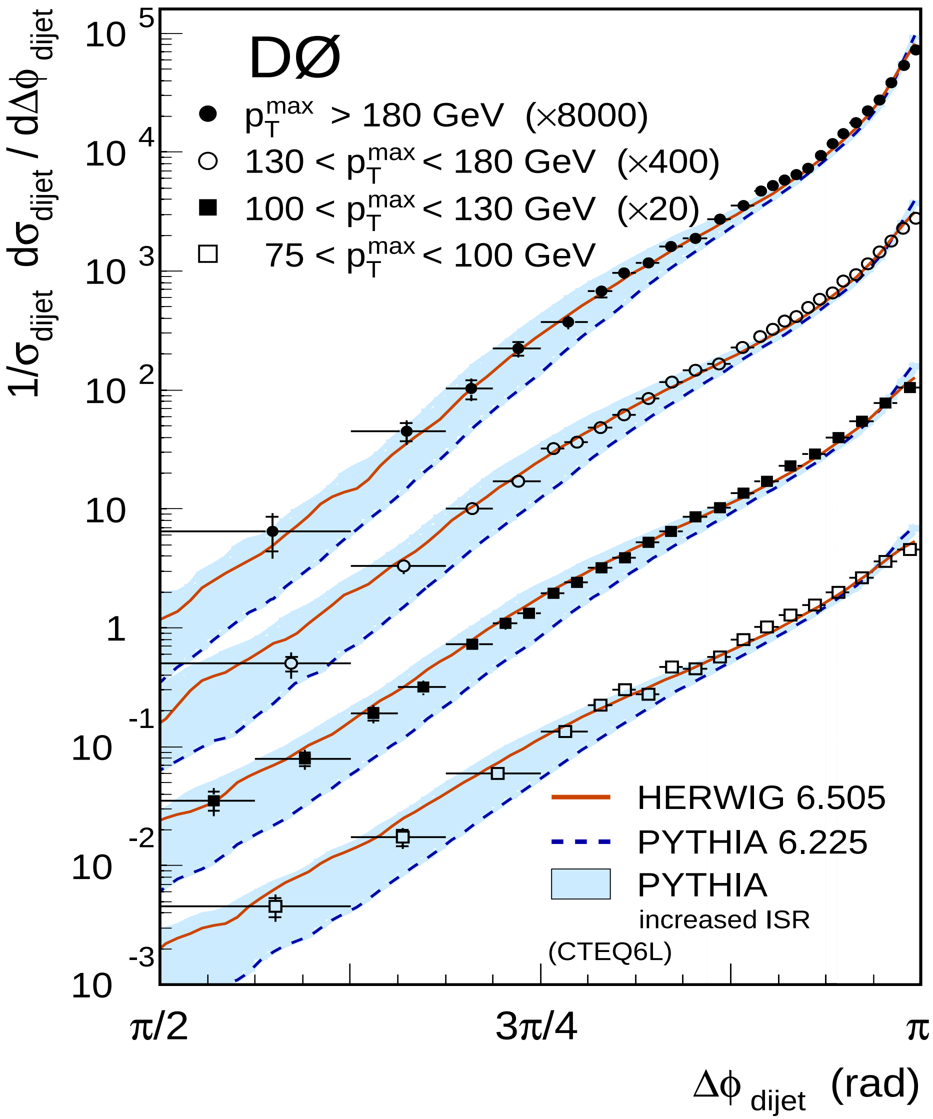
Dijet Azimuthal Decorrelations



- PDF uncertainty
  - Solid line, 5-10%
- Scale variation
  - Shaded area
  - larger for $\Delta\phi<2\pi/3$ (only tree-level 4-parton final states included)
- Fixed order pQCD fails at $\Delta\phi \approx \pi$ where soft processes dominate

NLO pQCD provides a good description of the data.

Dijet Azimuthal Decorrelations



- HERWIG 6.505 describes the data well
- PYTHIA 6.225 does not
- Tuning of PYTHIA allows for large variation of prediction
  - Shown here is range resulting from increasing ISR by a factor of 4.

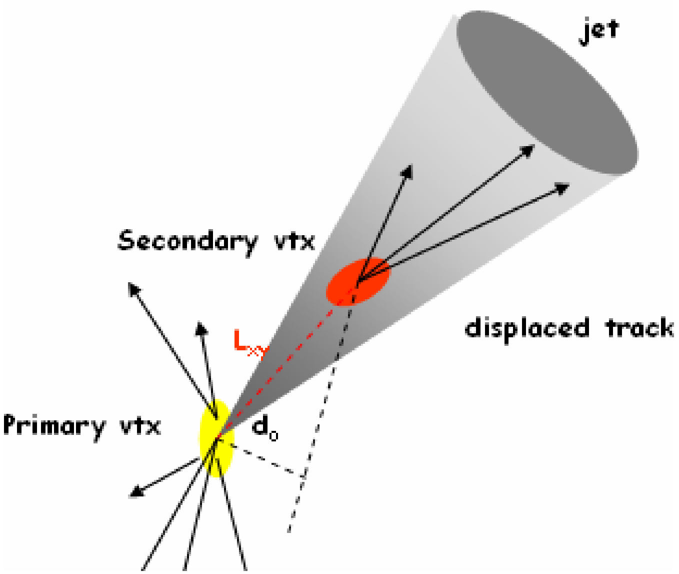
Data can be used to tune LO 2→2 pQCD ME + parton shower Monte Carlo generators

Inclusive b-jet Cross Sections

- Important quantitative test of QCD
  - large mass of b-quark justifies perturbative expansion in α_s
  - NLO pQCD expected to agree with data
- Extends upper reach of exclusive measurements using B-mesons
- Theoretical uncertainties on fragmentation and decay are smaller for the inclusive case
- Simple observable with high sensitivity to heavy flavor production up to highest p_T
  - Sensitive to new physics
  - Compositeness: third generation would show largest deviation from point-like SM behavior

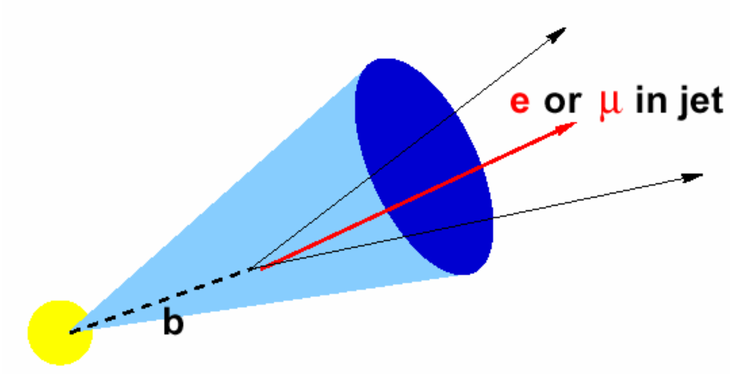
b-Jet Identification

- B hadrons travel Lxy~3mm before decaying with large charged track multiplicity
  - Look for displaced vertices



Secondary Vertex Tag

- b-quarks decay semileptonically
  - Leptons are softer and less isolated than the ones from W/Z bosons

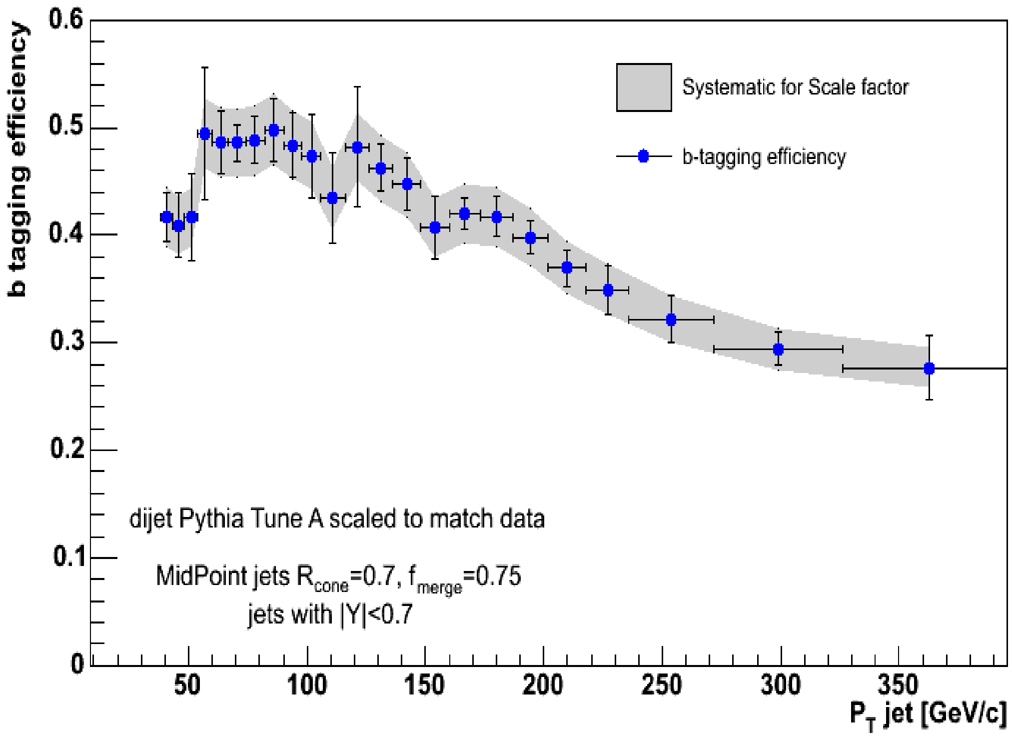


- $b \to \ell\nu c$ (BR $\sim$ 20%)
- $b \to c \to \ell\nu s$ (BR $\sim$ 20%)

Soft Lepton Tag

b-jet Cross Section

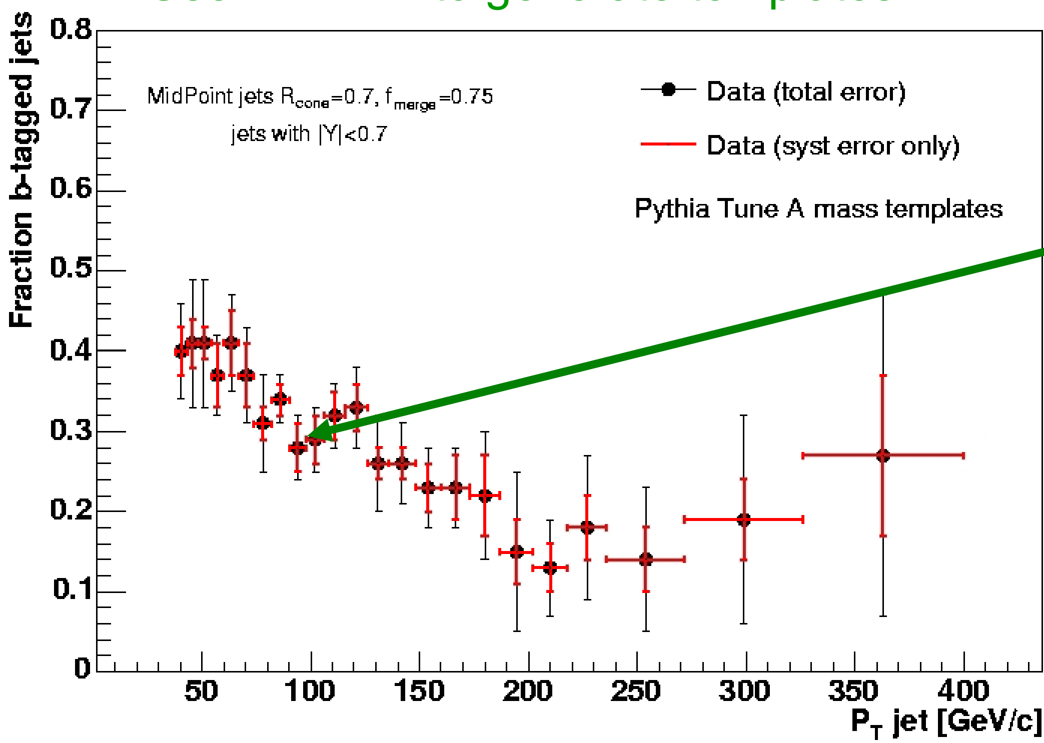
- Jets
  - $R_{cone} = 0.7$
  - $38 GeV < p_T < 400 GeV$
  - $|y| < 0.7$
  - Corrected for detector effects
- $\int \mathcal{L}\, dt \sim 300\ pb^{-1}$
- b-tagging
  - 2-dim SecVtx algorithm
  - Subcone R=0.4

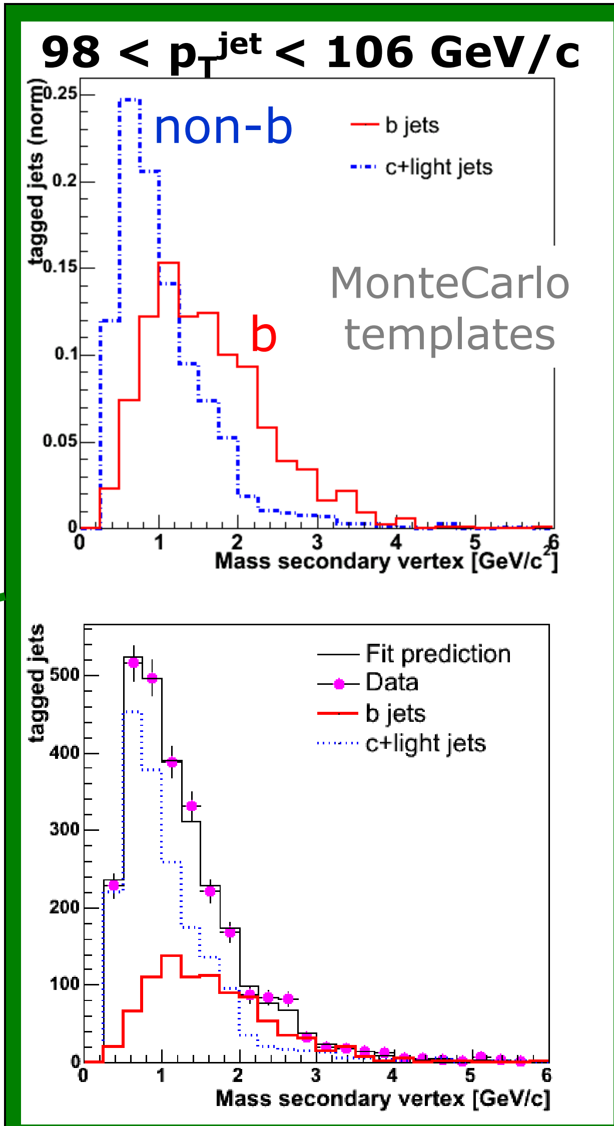


- b-tagging efficiency
  - measured in bins of jet p_T using a MC dijet sample
  - corrected with SF=Data/MC from inclusive electron sample

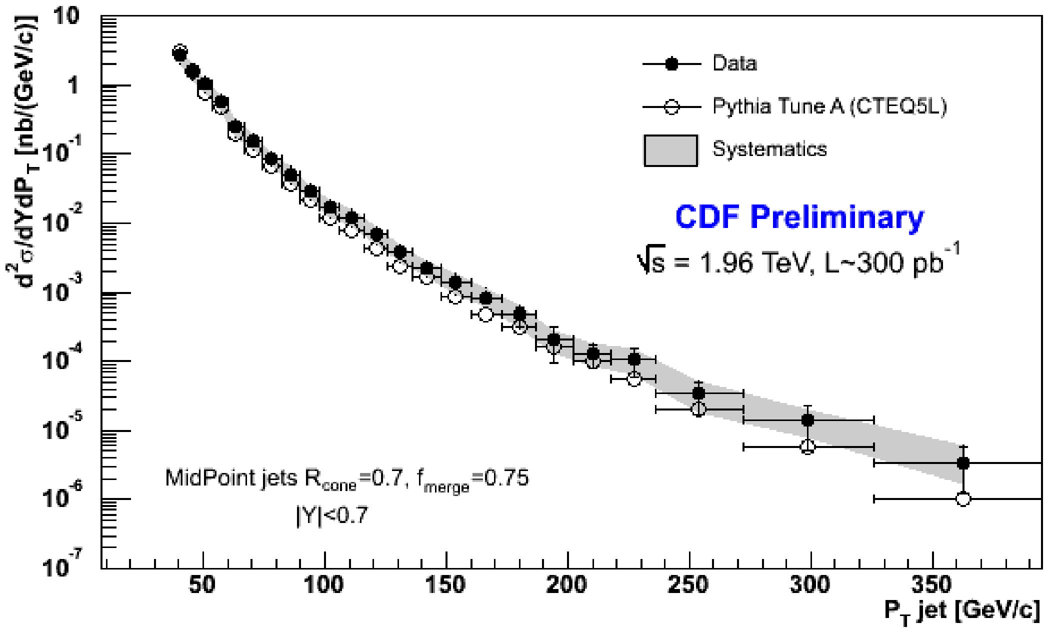
flavor composition of sample

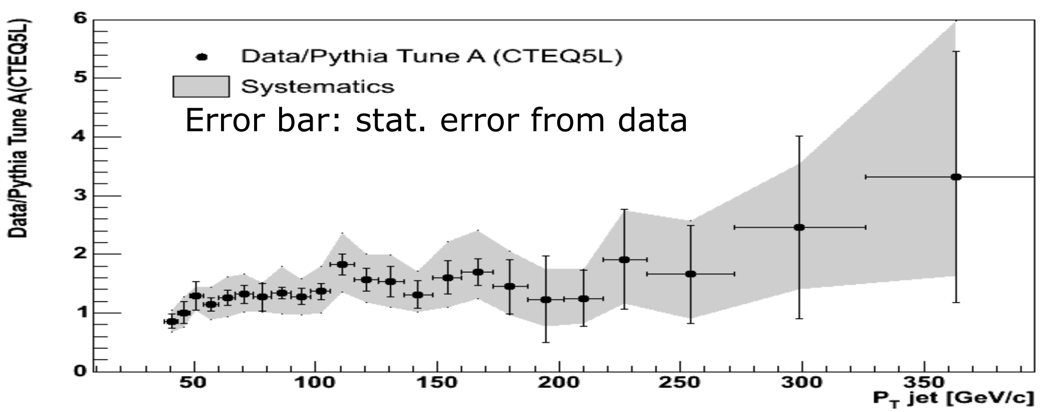
- Extract fraction of b-tagged jets from data using shape of mass of secondary vertex as discriminating quantity
  - bin-by-bin as a function of jet p_T
  - Use PYTHIA to generate templates





b-jet Cross Section



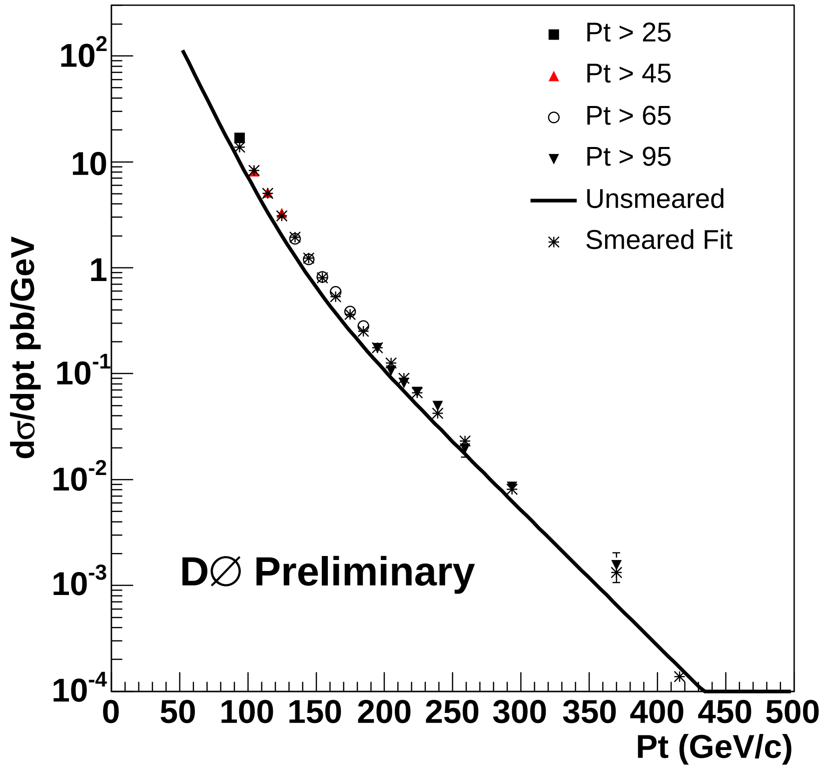


Systematic Error	low P_T	high P_T
Luminosity	6%	6%
Absolute Energy Scale	15-20%	40%
Jet energy resolution	6%	6%
B-tagging efficiency	10%	15%
B-tagged jets fraction	10-15%	40%
Unfolding	8%	8%

- Error on the last 6 bins dominated by b-tagged jets fraction
- Data/PYTHIA Tune A ~ 1.4 in agreement with expectation
- comparison with NLO coming soon

Inclusive μ-tagged Jets Cross Section

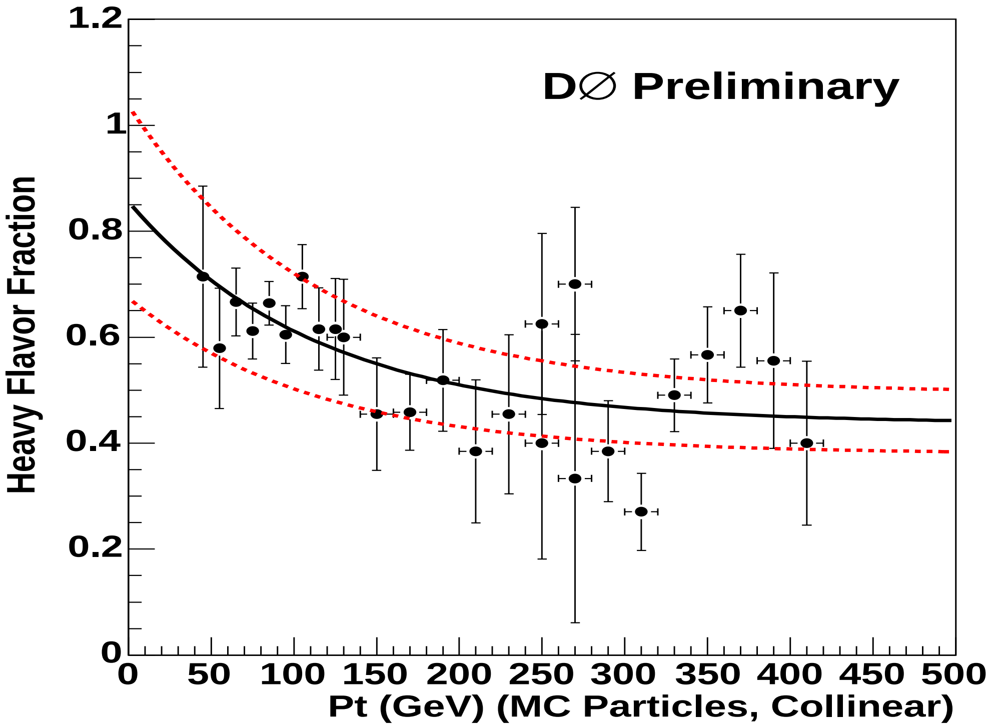
- Jets
  - Jet triggers (4 thresholds)
  - Rcone = 0.5
  - | ***y*** | < 0.5
- Muons
  - Track in Muon detector matched to Central track
  - p_T > 5 GeV
- DR(jet,μ) < 0.5
  - enhanced in HF jets
- $\int$L dt ~ 294 pb-1
- 4,460 jets with muons



Data is corrected by efficiencies and unsmeared by p_T resolution.

b/c μ-tagged Jets

- Inclusive μ-tagged cross section includes
  - b/c semi-muonic decays
  - in flight decays of Pions and Kaons (detector specific)
- Determine fraction of μ-tagged Jets originating from b or c quark decay from PYTHIA with full GEANT detector simulation

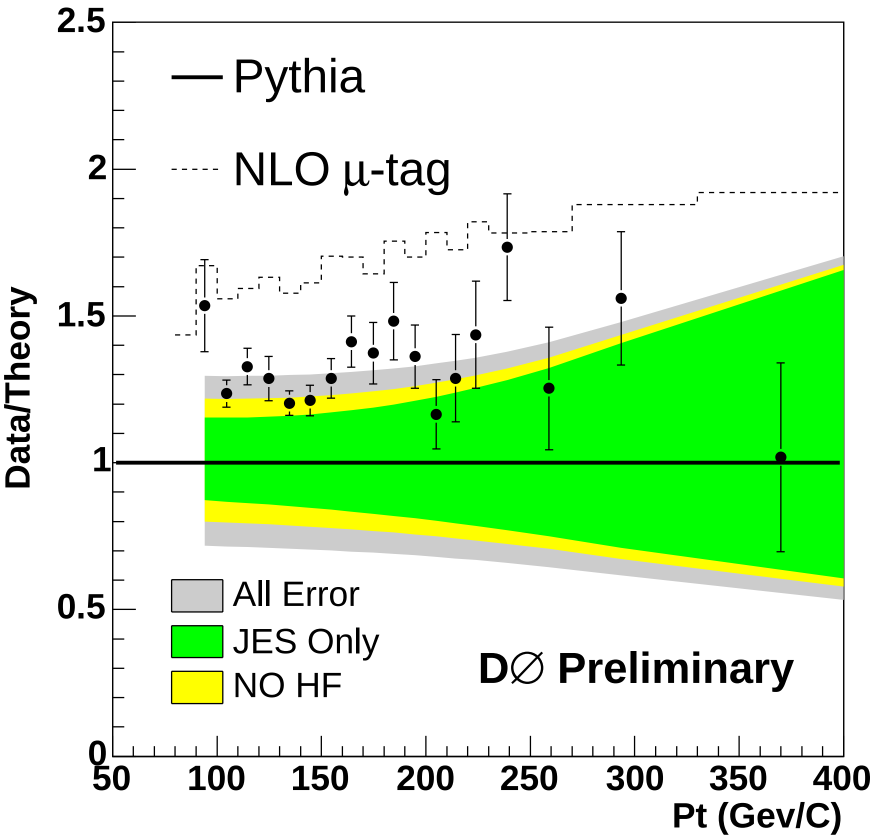


Large errors reflect limited MC statistics

Dashed error band is conservative 20%

μ-tagged b/c-Jets Cross Section

- Data unsmeared and corrected for fraction of μ-jets from b/c
- Result presented as a ratio with b/c jet x-sec from PYTHIA
- Compared with
  - PYTHIA
  - inclusive NLOJET++ jet x-sec corrected for fraction of μ-jets from b/c from PYTHIA
- experimental error dominated by JES
- At low p_T, HV content error becomes important



Data lies between the two calculations

Need to reduce the JES errors to compare to compositeness models

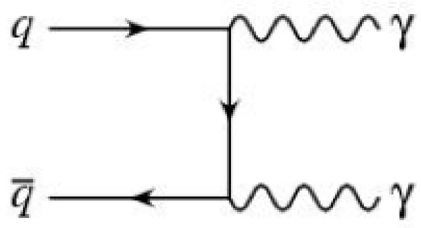
Photon Studies

- Dominant source of production for $p_T \lesssim 150$ GeV is prompt γ through Compton scattering $q + g \rightarrow q + \gamma$
  - Production cross section is sensitive to the gluon PDF
  - Test of NLO pQCD, soft gluon resummation and phenomenological models of gluon radiation & photon isolation.
- Signature of interesting physics
  - Di-photon final state is one of the main Higgs discovery channels at LHC
  - Possible signature of physics beyond the SM

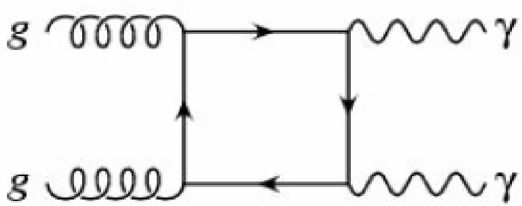
QCD production dominates:

understanding the QCD production mechanism is a prerequisite to search for new physics

Diphoton Production



High Mγγ



Low Mγγ

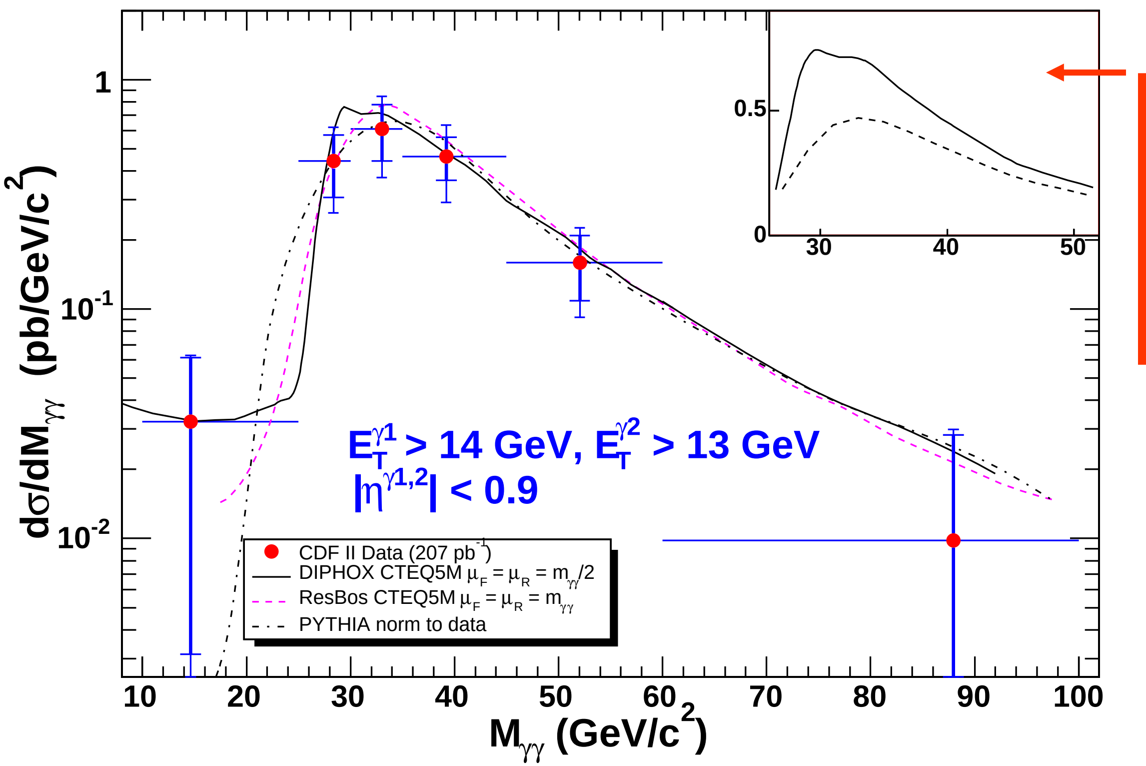
• gg process suppressed by a factor of α_s^2 , but noticeable at low di-photon mass.

• Background from neutral mesons (π^0, η) decaying to multiple photons

Accepted by PRL, hep-ex/0412050

- Two Isolated EM showers in calorimeter
  - No associated track
  - $|\eta| < 0.5$
  - E_T > 14 GeV & 13 GeV
- $\int \mathcal{L}\, dt \sim 207\ pb^{-1}$
- Background is statistically separated from signal based on differences in the EM showers in the CDF detector.
- Theoretical Predictions
  - PYTHIA (LO QCD)
  - DIPHOX (NLO QCD)
  - ResBos
    - Hard scatter at NLO
    - Fragmentation at LO
    - Resummation of ISR

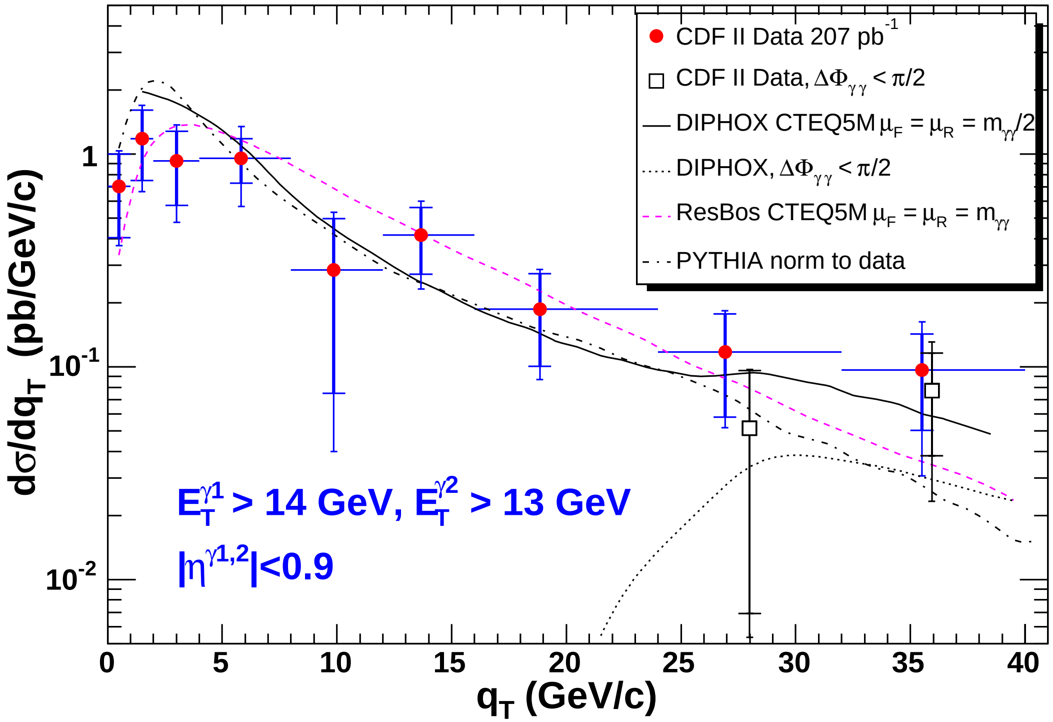
Diphoton Mass Distribution



- DIPHOX (solid)
- ResBos (dashed)
- PYTHIA (dot-dashed) scaled by a factor of 2

- Fairly good agreement between data and pQCD.
  - Low mass Diphoton production serves as interesting arena to study production from a gg initial state at the Tevatron.

p_T of Diphoton System



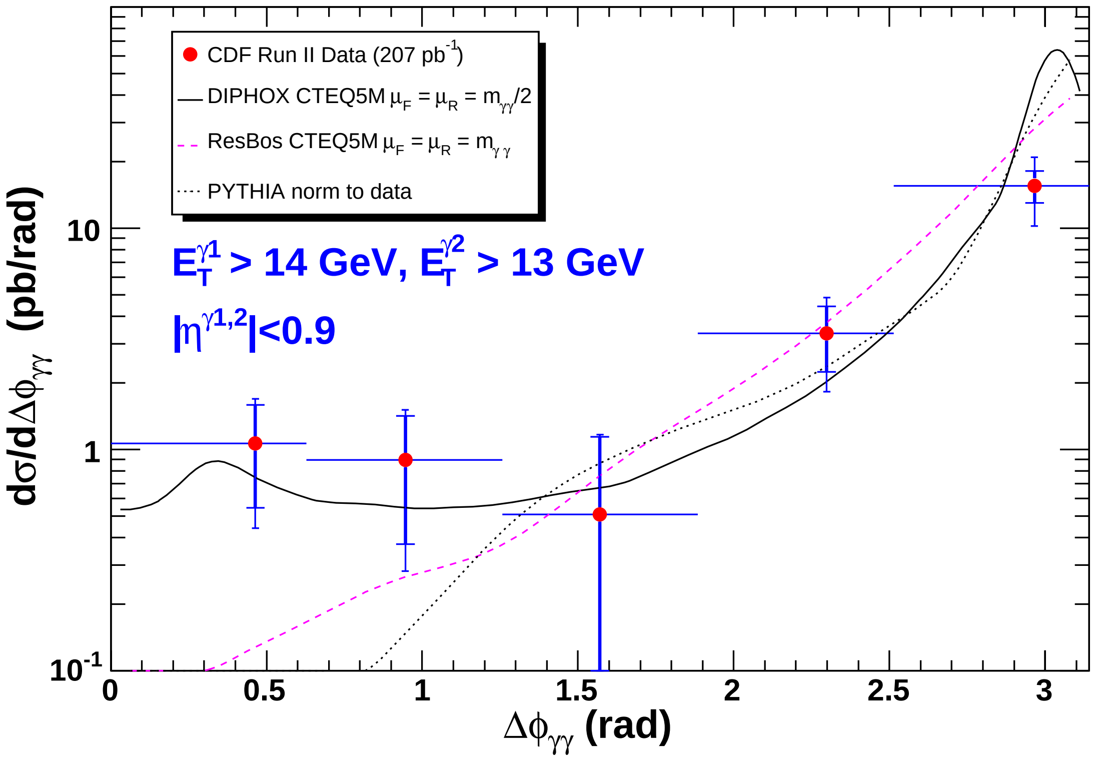
- DIPHOX (solid)
- ResBos (dashed)
- PYTHIA (dot-dashed) scaled by a factor of 2

AT LARGER pT

- DIPHOX (dot) & CDF data (open squares) when $\Delta\Phi < \pi/2$

- Low p_T region
  - DIPHOX Unstable (NLO calculation divergent)
  - RESBOS (includes soft gluon resummation) describes data
- High p_T region
  - Fragmentation included at NLO (DIPHOX) and LO (ResBos). Extra phase space accessible at NLO to DIPHOX results in 'shoulder"

Δφ between the 2 Photons



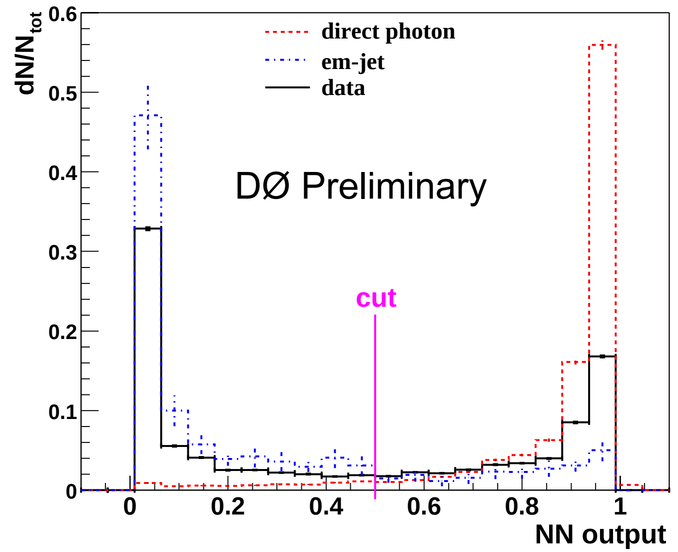
- DIPHOX (solid)
- ResBos (dashed)
- PYTHIA (dot-dashed) scaled by a factor of 2

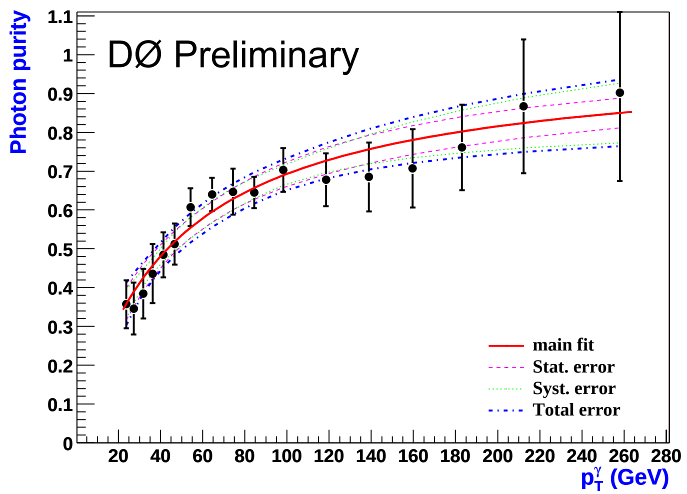
- Low Δφ region
  - NLO contributions, better agreement with DIPHOX
- High Δφ region
  - Gluon resummation contributes, better agreement with ResBos

Overall, Diphoton data is consistent with pQCD predictions

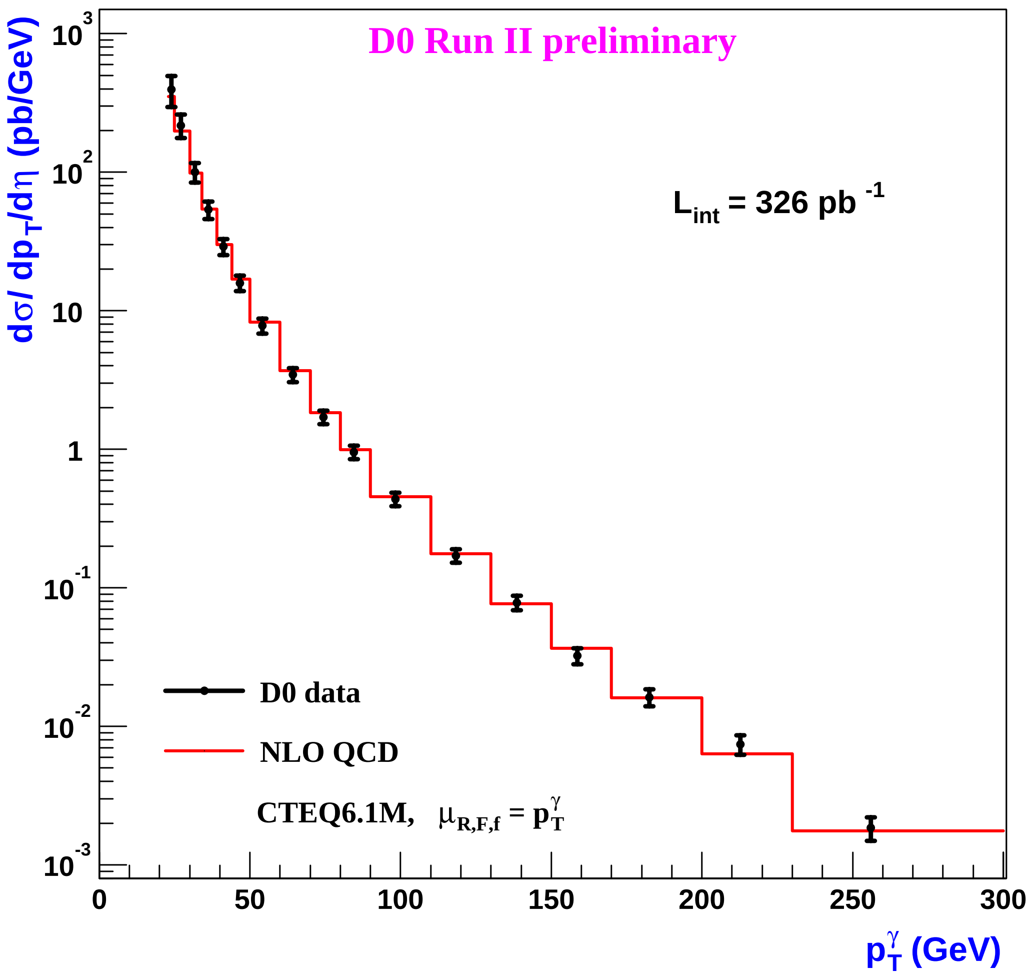
New Isolated Photon Cross Section

- At least one Isolated EM shower in calorimeter
  - No associated track
  - $|\eta| < 0.9$
  - $E_T > 15$ GeV
- $\int \mathcal{L}\, dt \sim 326\ \mathrm{pb}^{-1}$
- NN is trained to discriminate between signal and EM jets
  - Keep events with NN output > 0.5
- Photon purity obtained from fit to NN output in data to MC predictions for signal and EM jets from data.





New Isolated Photon Cross Section

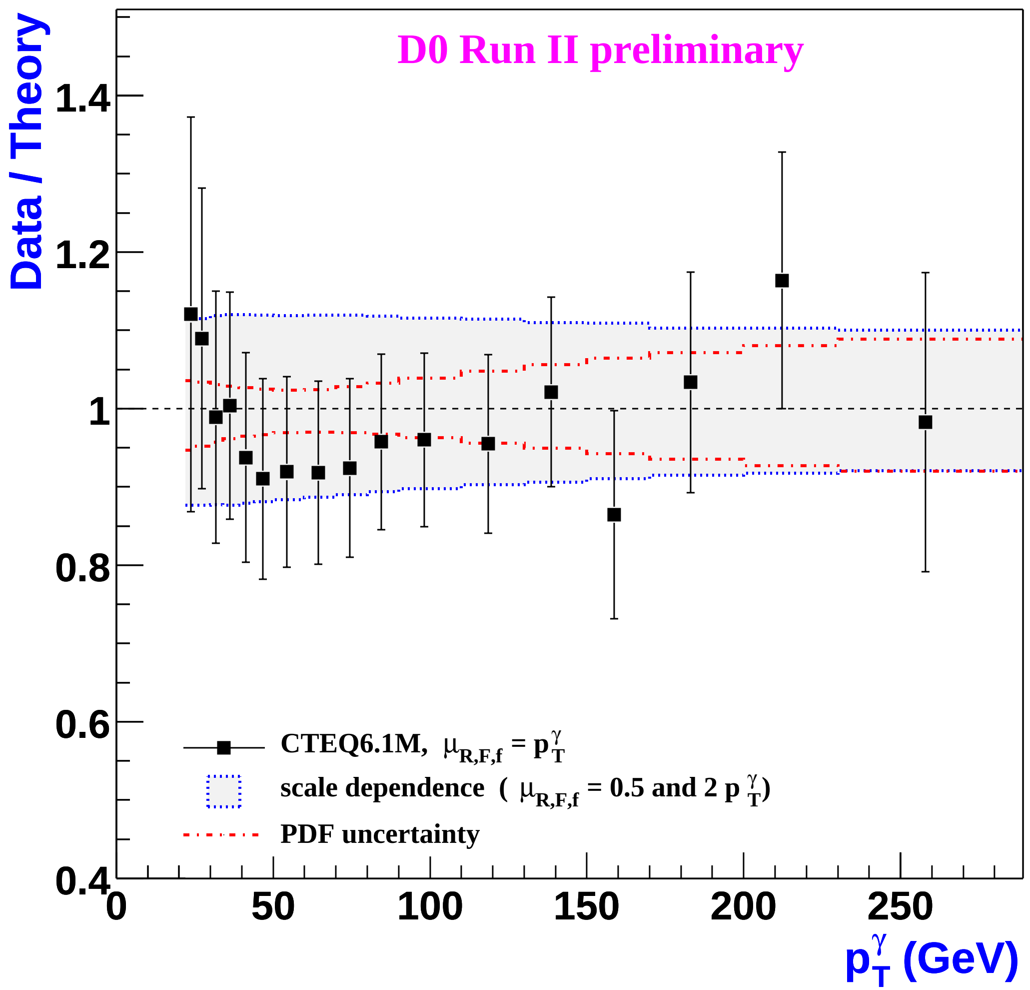


$$\frac{d^2\sigma}{dp_T^\gamma d\eta^\gamma} = \frac{N_{umber}\, P_{urity}\, f_{unsmear}}{L\,\Delta p_T^\gamma\, \Delta\eta^\gamma\, A\,\varepsilon}$$

- Data shown with Stat + Syst Errors & unfolded for calorimeter resolution.
- Theory is NLO QCD prediction from JETPHOX, with $\mu_{F,R,f} = p_T(\gamma)$ and CTEQ6.1M

Prediction describes Data within experimental uncertainties

Isolated Photon Cross Section



Good agreement with NLO QCD with CTEQ6.1M (from JETPHOX)

Prediction from Gordon and Vogelsang (1993) within 7%

Conclusions and Outlook

- Dijet Azimuthal Decorrelation was measured in different ranges of leading jet p_T
  - Increased decorrelation towards greater p_T
  - NLO pQCD describes data well except at large $\Delta\phi$ where calculation is not predictive
  - Data can be used to tune Monte Carlo Event Generators
- Inclusive b-jet x-sec SecVtx & μ tag
  - Preliminary results show no surprises
  - Working towards improved analysis techniques and comparisons with theory
- Photons
  - General agreement with NLO pQCD predictions

Understanding QCD is not only important in itself, but crucial for many SM measurements and searches for new physics